Agricultural Electrostatic Spraying

Subjects: Agricultural Engineering

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Agricultural electrostatic spraying technology is superior to non-electrostatic spraying technology. Electrostatic droplets have better “adhesion, penetration, and encircling ability” in crops. Electrostatic spraying technology is used to charge droplets to induce an electric field on the surface of the crop leaves, thus adsorbing electrostatic droplets and achieving directional movement of the charged droplets.

droplet retention electrostatic spraying crop leaves moisture content capacitance

1. Introduction

The attraction of the electric field on the crop surface to the charged droplets can be divided into two cases. The first is the group of charged droplets attracted to the plant surface, which facilitates the target movement of the droplets toward the crop. In the second case, when the droplets are close enough to the crop, the attractive forces are sufficient to overcome the gravitational, inertial and drag forces on the droplets, changing their trajectory and inducing them to move towards the target plant and adhere to its surface, thus increasing the adsorption force.

Currently, electrostatic spraying systems and parameter optimization, charged droplet–environment interactions, and target parameters are the three main aspects of research on plant protection electrostatic spraying technology [1][2]. Research on electrostatic spraying systems and parameter optimization has focused on electrostatic nozzle development [3][4], charging effect [5], atomization mechanism, and operational parameters [6][7]. For droplet charging there are mainly three approaches: corona charging, inductive charging, and contact charging. Among these, contact charging has a good charging effect and is widely used in backpack electrostatic sprayers, whose operating voltage is generally 10~30 kV.

The interaction between charged droplets and the environment is mainly focused on relative temperature and humidity, airflow rate [8], electrostatic force [9][10], and fluid simulation [11]. The study of target crop parameters at the whole-plant scale has focused on the effects of canopy shape [12], size and leaf area index [13], and electrostatic spraying; at the leaf scale, the effects of leaf material and leaf inclination have also been investigated. Using a 0.5 mm-thick aluminum plate as the simulated crop leaf material, spray deposition was used as an evaluation index to study the electrostatic droplet deposition at different leaf inclination angles (relative to the horizontal plane) on the spray droplet deposition effect; it was found that deposition increased with the increase in leaf inclination [6]. The deposition of droplets on different materials was also investigated and it was found that deposition decreases in the order of metals, real leaves and plastic materials [14]. Therefore, leaf material is important for the establishment of the electric field, droplet adsorption, and current conduction-induced electric field on the leaf; this is understood to be caused by differences in the leaf dielectric parameters.

Several studies have reported a positive correlation between leaf dielectric constant and leaf water content [15][16][17]. The dielectric constant is a function of various factors including plant type and age, soil nutrient level, leaf solute concentration, and leaf water content. Usually, leaf dielectric constants are attributed to resistance and capacitance [15]. During agricultural electrostatic spraying, the electric field created by charged droplets moves ions in the plant tissue and collects charges of opposite polarity to the charged droplets on the leaves, thus increasing the capacitive effect of the leaves [18]. Therefore, the effect of leaf capacitance on electrostatic spraying is very important. Leaf capacitance values are often used to measure the water content of plant leaves and are considered to be a function of the water content within the leaf and the measurement frequency [19][20][21]. A capacitive sensor with a parallel capacitance plate was used to measure the water content of leaf slices. A positive correlation between sensor capacitance and leaf water content was observed at different measurement frequencies (100 kHz and 1 MHz) [17]. Changing the leaf water content to achieve a change in the control of the leaf dielectric constant (capacitance value) was applied in this study. Additionally, the capacitance sensor has the advantages of high measurement accuracy and non-invasiveness. Using the capacitive method to measure the dielectric constant of the leaf, the leaf is not damaged and continuous measurement of the leaf-holding capacity and water content can be ensured [22][23]. Therefore, in this study, we investigate the law of the effect of this change on electrostatic spraying technology by changing the leaf water content, causing a change in leaf capacitance.

The agricultural spraying process is divided into deposition, retention, absorption, and transfer [24][25], of which retention is a key indicator of the effectiveness of agricultural spraying technology. A variety of factors can affect the retention of electrostatic droplets on the crop surface. The studied factors are mainly focused on plant characteristics and droplet properties. Droplet retention is also strongly dependent on the type of leaf surface and microstructure [26]. A large number of plant species, including weeds and crops as well as fruits and leaves, have been investigated in order to predict spray droplet retention [27]. Herein, the effects of multiple leaf surface properties and variations in leaf capacitance on electrostatic spray deposition efficiency are considered.

2. Influence of Plant Leaf Moisture Content on Retention of Electrostatic-Induced Droplets

In the process of agricultural spraying, the application of electrostatic spraying technology can improve retention on a variety of crops. Herein investigated the positive correlation between crop leaf water content and electrostatic droplet retention, i.e., that the retention of electrostatic droplets on the leaves of a variety of crops gradually decreases with a decrease in leaf water content.

2.1. Leaf Water Content and Leaf Capacitance

The plant leaf crop is a dielectric whose conductive properties are between those of a conductor and an insulator. Upon attachment of charged droplets to the leaf surface, an electric field is formed outside the leaf and, under the action of the electric field, the internal solution of the leaf corresponds to a capacitive medium and exhibits a specific capacitance value [28]. Water is usually present in plant cells in the form of bound and free water. The free water content limits the metabolic intensity of the plant, while bound water is not involved in metabolism [29]. Therefore, changes in leaf water content inevitably cause changes in the dielectric constant, which in turn are reflected by the leaf capacitance values [30]. Therefore, plant leaves are often used as an effective site for testing characteristic electrical parameters [31]. In this paper, crop leaves were set up as dielectric plates placed between two plates of a parallel plate capacitor.

The magnitude of capacitance can be expressed by the ratio of the amount of charge, Q, between the two plates to the potential difference, U, given as

$$C = Q/U \tag{1}$$

However, when the dielectric slab (crop leaf in the current paper) is installed between the capacitor, dielectrics are polarized due to the potential difference between the two plates of the capacitor, and a dipole moment is induced in the interior. A negative polarization charge is induced on the surface of the dielectric on the positive side of the plate; conversely, a positive charge is induced on the negative side of the plate, and the opposite electric field is produced in the dielectric interior, which weakens the potential difference between the charged electrode plates and increases the capacitance of the capacitor. For the dielectric slab, capacitance can be calculated by the following formula:

$$C_x = \epsilon_r \epsilon_0 A/4k\pi\delta = \epsilon_r C_0 \tag{2}$$

where C_0 is the capacitance of the capacitor when there is vacuum between the plates; C_x is the capacitance with dielectric slab added between the capacitor plates and the plate distance is the same as when C_0 is measured; *k* is the electrostatic force constant; k is the effective covering area of the dielectric slab; A is the distance between the parallel plates of the capacitor; δ is the relative dielectric constant; and ϵ_r is the dielectric constant of the capacitor when there is vacuum between the plates.

Tomato, pepper, and winter wheat leaves were studied and leaf capacitance was measured using an LCR tester followed by leaf water content measurement using the drying method. In this paper, a linear relationship between leaf water content and leaf capacitance was calculated by statistical correlation and regression methods for the three crops. However, the linear relationship between leaf capacitance and leaf water content is highly dependent on the growing environment of the crop, such as light conditions, the type of nutrient solution, and culture substrate. Light stimulates the opening of leaf stomata, which in turn increases photosynthesis in leaves, leading to changes in solute content in leaves that have various effects on the dielectric constant in solution [22]. Usually, increasing the concentration of solute in leaves decreases the dielectric constant in solution [21], which is consistent with the conclusion obtained in this paper, namely that after sufficient watering of the crop and as environmental water decreases, the crop's own water also gradually decreases, leading to an increase in the concentration of solutes in the leaves and resulting in a decrease in leaf capacitance. However, whether the relationship between the reduction in leaf water content and the change in leaf capacitance is linear or exponential needs to be measured and calibrated to the various culture environments of the crop.

2.2. Electrostatic Droplet Holding Capacity

Herein shows that water content has a significant and important effect on the retention of electrostatic droplets on crop leaves. Maximum retention occurs at the highest water content of the leaves and decreases as the water content of the leaves decreases, which means that the retention capacity of the leaves decreases. This phenomenon shows the same pattern in different plant types. For tomato leaves, in the highest water content state (leaf water content of 90.06%) the retention amount per unit area of the leaf increased by 5.7 $\mathrm{mg}/\mathrm{cm}^2$; considering the area of tomato leaves, the retention amount can be increased by 75.582~85.728 mg, and the retention amount on a single leaf is about 2577 mg. In other words, when agricultural electrostatic spraying is carried while out considering the state of water content, the spraying effect of a single leaf can be increased by 2.93%.

For pepper leaves, in the highest water content state (leaf water content of 88.86%), the retention amount per unit area of the leaf increased by 6.1 $\mathrm{mg}/\mathrm{cm}^2$; considering the pepper leaf area, the retention amount can be increased by 136.335~160.735 mg and the retention amount on a single pepper leaf is about 2206 mg. As such, the spraying effect of a single leaf can be increased by 7.29% when considering the state of water content when conducting agricultural electrostatic spraying.

For winter wheat leaves, in the highest water content state (leaf water content of 86.78%), the retention amount per unit area of leaves increased by 5.4 $\mathrm{mg}/\mathrm{cm}^2$; considering the area of the leaves, the retention amount can be increased by 71.604~81.216 mg and the retention amount on a single leaf is about 1992 mg. In other words, the spraying effect on a single leaf could be increased by 3.59~4.07% when considering the state of water content when conducting agricultural electrostatic spraying.

The effects of leaf and electrostatic voltage on the droplet retention of different crops were also verified in this paper. When comparing different crops, the retention capacity of tomato leaves was the highest, the droplet retention capacity of pepper leaves was the lowest, and winter wheat was in between these values. Additionally, increasing the electrostatic spraying voltage significantly improved droplet retention on the leaf surface of different crops. Tomato leaves have sparse, glandular hairs, and droplets falling into these glandular structures spread rapidly on the leaf surface, increasing droplet adhesion [25]. However, as the electrostatic voltage increases, the maximum retention on the crop leaves increases. The trend in increasing retention on tomato leaves was evident; however, retention on the other two crops increased slowly. At 10 kV, the maximum retention on pepper leaves was approximately equal to that on winter wheat, but lower than that on tomato. When the electrostatic voltage increased to 20 kV, the maximum retention on winter wheat leaves exceeded that on pepper; at 30 kV, the maximum retention on winter wheat leaves increased to 1.2 times that on pepper. This was due to the waxy and border folds on the pepper leaves; however, the winter wheat leaves had short and hairy auricles, narrow, lance-shaped leaves, and depressed main veins, which collected droplets.

3. Conclusions

Herein, the effects of water content on leaf retention and the trend in leaf retention at different electrostatic voltages were investigated. The main findings were as follows:

(1) A linear function between water content and leaf capacitance was established for three crops—tomato, pepper, and winter wheat—and the water content of crop leaves were obtained without loss.
(2) From the perspective of crop leaf surface retention, electrostatic spraying technology proved itself to be superior to non-electrostatic spraying technology. The retention capacity of electrostatic spraying increased with an increase in leaf water content, and the retention capacity of non-electrostatic spraying conditions decreased with an increase in water content.
(3) Increasing the electrostatic spraying voltage had a significant effect on the retention capacity of leaves. Within a certain voltage range (0~30 kV), increasing the electrostatic spraying voltage improved the retention of droplets on the leaves of the different crops.

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